

Project Prometheus Frequently Asked Questions December 2003

What is Project Prometheus?

NASA's Mission to understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers requires that we make strategic investments in technologies that will transform our capability to explore the Solar System and beyond. Within the Space Science Enterprise, we are developing the tools, insights, and abilities necessary to answer some of humanity's most profound questions: How did the Universe begin and evolve? How did we get here? Where are we going? Are we alone?

In Greek mythology, Prometheus was the wisest of the Titans who gave the gift of fire to humanity. The word "Prometheus" is synonymous with "forethought," an idea that embodies NASA's hope to establish new tools for expanding our exploration capabilities.

NASA believes that, in the field of space exploration, answering these questions translates to constantly striving to develop innovative scientific instruments and more effective ways to safely power, propel, and maneuver spacecraft, as we explore the worlds beyond our current reach. Achievement of this ambitious vision requires a bold approach to the next generation of solar system exploration missions, including revolutionary improvements in energy generation and use in space.

Project Prometheus, the Nuclear Systems Program, is making strategic investments in near- and long-term nuclear electric power and propulsion technologies to maintain our current space science capabilities and that would enable space exploration missions and scientific returns never before achievable. In addition to developing the next generation of radioisotope power systems, the predecessors of which have been used for over 30 years to power space science missions, Project Prometheus would develop and demonstrate the safe and reliable operation of a nuclear reactor-powered spacecraft on a long-duration space science mission. Toward this end, the proposed Jupiter Icy Moons Orbiter (JIMO) mission has been identified as the first space science mission that would incorporate these new revolutionary technologies.

What is the Jupiter Icy Moons Orbiter?

Project Prometheus is developing a proposed space science mission, the Jupiter Icy Moons Orbiter, that would enable detailed scientific investigation and data return from the icy moons of Jupiter -- Callisto, Ganymede and Europa -- that may have three ingredients considered essential for life: water, energy and organic material. Making use of nuclear fission power and electric propulsion, the

mission would involve one spacecraft orbiting, at close range and for long durations (months at a time), these three planet-sized moons. The spacecraft would orbit each of these moons for extensive investigations of their makeup, history, and potential for sustaining life.

In addition to enabling an entirely new class of scientific investigations, the mission would also demonstrate the safe and reliable use of a space nuclear reactor in deep space for long-duration space exploration. The amount of power available from a nuclear reactor – potentially hundreds of times greater than that available to current interplanetary spacecraft -- would enable delivery of larger payloads with vastly more capable instruments and faster data transmission back to Earth than such missions as Voyager, Galileo, and Cassini. In addition, because extremely fuel-efficient electric thrusters would propel the spacecraft, mission planners could make course adjustments throughout the mission in response to real-time discoveries.

How will the Jupiter Icy Moons Orbiter get to Jupiter?

After being launched from Earth by a traditional chemical rocket, the spacecraft would rely on an electric propulsion system, e.g., a system expelling electrically charged particles called ions from its engines to generate thrust. Powered by a small nuclear reactor, the electric propulsion system would propel the spacecraft to the Jovian system and then insert the spacecraft into orbit around, successively, each of Jupiter's three icy moons. In 1998, NASA's Deep Space 1 mission successfully demonstrated the use of ion propulsion for interplanetary travel.

Why do you need to use a nuclear reactor to get to Jupiter?

The large quantities of power generated by the compact nuclear reactor (about the size of a 5-gallon bucket) enable a variety of advanced mission capabilities, and therefore increased scientific return, not possible with conventional power systems.

To start, access to high levels of continuous power enables full-time maneuverability of the spacecraft. After being launched from Earth, using conventional chemical rockets, the spacecraft would use fuel-efficient electric thrusters to propel it to Jupiter. Once in the Jovian system, the engines would propel the spacecraft to each moon where controlled, close-range orbits would provide ideal conditions for science observations. Moreover, the maneuverability afforded by nuclear power and electric propulsion would enable mission scientists to alter mission plans based on real-time discoveries. Such maneuvers are not possible with current chemical propulsion systems, which consume the bulk of their propellant during departure from Earth. Once outside Earth's gravitational influence, such conventionally powered spacecraft coast to

their destination, making very limited adjustments to their trajectories using relatively inefficient chemical combustion for propulsion.

Electric propulsion should also enable delivery of significantly heavier, and in most cases larger, payloads to destinations throughout the solar system and beyond. Because the electric propulsion system would consume fuel very efficiently, it could be used throughout the mission to gradually accelerate the spacecraft and its unprecedented scientific payload to high velocities.

Either in transit or at its final destination, the reactor could power high-capability, active science instruments never before used beyond Earth orbit. Another benefit is that space scientists could operate these instruments simultaneously rather than cycling them as is currently the practice due to limitations in the power available on present-day exploration missions.

Finally, the reactor would power the spacecraft's communications equipment, which would transmit the voluminous science data acquired by these instruments back to Earth in quantities and speeds never before possible.

Why are Jupiter's icy moons a priority (i.e., what is the scientific justification)? What are the science goals?

Exploring the Universe and searching for life are central to NASA's mission, and Jupiter's large icy moons appear to have three ingredients considered essential for life: water, energy and the necessary chemical elements. NASA's Galileo spacecraft found evidence for subsurface oceans on these three moons of Jupiter – a finding that ranks among the major scientific discoveries of the Space Age.

The National Research Council (NRC) completed a report last year, based on input from the planetary science community, that prioritized potential flight missions for exploring the solar system. It ranked an "Europa geophysical explorer" mission as its top priority for a "flagship" mission, based on the Galileo data suggesting a liquid ocean under Europa's ice crust. The Jupiter Icy Moons Orbiter mission would build upon and exceed the NRC's recommendation by not only conducting in-depth investigations of Europa, but because of the propulsion capabilities of the spacecraft, it would also examine Callisto and Ganymede, providing comparisons key to understanding all three.

The Jupiter Icy Moons Orbiter mission has four major science goals:

1. Determine the interior structures of the icy moons of Jupiter in relation to the formation and history of the Jupiter system;
2. Determine the evolution and present state of the Galilean satellite surfaces and subsurfaces, and the processes affecting them;

3. Determine how the components of the Jovian system operate and interact, leading to the diverse and possibly habitable environments of the icy moons;

4. Determine the habitability of Europa and the other icy moons of Jupiter.

How much fuel will be used in the reactor?

The amount of fuel needed for the proposed reactor would depend on the final reactor design. However, based on a reference power level of 100 kilowatts (electric power), the reactor would be quite small: the entire reactor core could fit within a 5-gallon drum. Each of the reactor design concepts currently being considered could have from 100 to 150 kilograms or approximately 220 to 330 pounds of uranium fuel.

How hazardous would it be if there were an accident in space and the reactor explodes?

The reactor will be designed with multiple safety features that will prevent uncontrolled, sustained nuclear fission (which could disassemble the reactor) before, during or after launch of the spacecraft. Moreover, the space reactor would be designed to remain intact over a broad range of ground and in-space accidents.

How often will a mission similar to the Jupiter Icy Moons Orbiter be mounted?

It is planned that the Jupiter Icy Moons Orbiter mission would be the first of many scientific missions enabled by nuclear electric power and propulsion. Specifics regarding any future missions would be dependent on NASA's exploration requirements, developed in consultation with the scientific community. It is expected that the technologies developed by Project Prometheus could support future space exploration missions, including human exploration of space.

What will be the operations cost for the JIMO mission and how long will those costs continue?

The operational cost will be highly dependent on the method chosen to implement the Jupiter Icy Moons Orbiter mission. When the initial mission studies are completed in FY05, NASA expects to be in a better position to provide accurate and complete project life cycle cost estimates, including operational costs.

What confidence do we have that the systems developed for the JIMO mission will work?

NASA is very confident in its ability to design and build systems that will meet all mission requirements and be ready to launch by the early part of the next decade, assuming that the required funding is received. The technical hurdles, while significant, do not require major breakthroughs but can be managed with a focused and consistent engineering effort by the nation's R&D community.

Where will we get the enriched uranium for the JIMO reactor?

The uranium-235 for the fission reactor would come from current federal government stocks owned and managed by the Department of Energy.

What is the total cost of this mission? Why is it so expensive?

NASA's funding estimates reflected in the President's FY04 budget run out through FY08 includes roughly \$3 billion for Project Prometheus, with just over \$2 billion of that directed toward the technology development for the Jupiter Icy Moons Orbiter and similar missions. NASA expects to be able to provide more accurate and complete project life cycle cost estimates when initial mission studies are completed in FY05.

The Jupiter Icy Moons Orbiter mission would be the most capable deep space science mission ever launched by NASA, with revolutionary new capabilities enabled by the power available from its space nuclear reactor. NASA views Project Prometheus and the JIMO mission as strategic investments necessary to expand our capabilities to effectively support our mission of exploring the universe and searching for life.

What scientific payload could justify the expense of such a mission?

Presently, because of power limitations, outer solar system exploration missions have been limited in their science capabilities and, therefore, their science return. Project Prometheus is NASA's strategic investment in technologies that could provide the science community with the energy supply necessary, practically anywhere in the solar system, to dramatically increase science opportunities and the quality of science conducted throughout a mission. .

Because of the power available from a space nuclear reactor, the spacecraft would be able to carry instruments with capabilities far beyond those flown in previous outer solar system missions, including high-power, active instruments as well as instruments of much greater precision and resolution that would generate orders of magnitude more data than current missions with significantly smaller power sources. Examples of such instruments are high-power radars that could penetrate deep into the subsurface of the three moons (10s of kilometers) in search of liquid water, more capable cameras and spectrometers with greater resolution (200 colors vs. 7 colors or less than 100 meters per pixel vs. 100 km per pixel) to map nearly the entire surface of each moon, and instruments that

use lasers to measure the topography of, or to illuminate, extraterrestrial surfaces. Moreover, as opposed to current missions where instruments are cycled on and off, the nuclear-powered spacecraft would have the capability to power all its science instruments, if desirable, simultaneously.

When assessing the science potential of a mission, one must look not only at the scientific payload, but also at how these instruments can be used throughout the mission. Nuclear electric power and propulsion technologies are being studied because they have the potential to enable close-range observations of multiple destinations for extended periods of time in a single mission; to adjust mission objectives in response to real-time discoveries, and to transmit huge amounts of data back to Earth.

Specific science instruments have yet to be identified for the proposed JIMO mission. To facilitate this process, NASA is working with the science community via a Science Definition Team, to identify specific science objectives for the mission and the measurements necessary to support these objectives. In addition, NASA has begun a new program dedicated to developing the new high capability instruments that would be possible on the potential JIMO mission. Final determination of science instruments would be carried out through an Announcement of Opportunity (AO), which would provide the science community an opportunity to formally propose specific instruments and measurements.

How will you ensure planetary protection at Europa?

NASA's Office of Space Science will work with the NASA Planetary Protection Advisory Committee to develop guidelines for planetary protection requirements for Europa. For example, this mission would be designed to reduce the probability that the spacecraft would strike Europa at any stage of the mission.

Why can't this mission be done with solar electric propulsion and solar sails?

Solar arrays would have to be far too large to produce the electrical power required to operate the electric propulsion system and scientific instruments for the Jupiter Icy Moons Orbiter mission. The Sun's energy at Jupiter is less than 1/25th of its level at Earth, which make this type of mission virtually impossible to perform with solar arrays, even taking into account expected improvements in solar array efficiency in the foreseeable future.

NASA is researching the ability of solar sails (not to be confused with large solar arrays) to enable low mass spacecraft to achieve large increases in velocity by using the pressure of sunlight to fill a lightweight sail, thereby "pushing" the spacecraft. Solar sails may one day be used to propel small spacecraft to the outer solar system, but presently their most effective use appears to be within a 'zone' no more than twice the Earth's distance from the Sun. Therefore, solar

sails are not a viable option for propelling a JIMO-like spacecraft to Jupiter, let alone maneuvering it around Jupiter's three icy moons.

What is the Department of Defense's role in this program? Is NASA really just a front for DoD in their desire for fission-powered space weapons?

While NASA maintains open lines of communication with various components of the federal government, DoD has no role in this program. Project Prometheus program requirements have and will continue to be established to meet NASA's science and technology needs for space exploration.

Meanwhile, NASA works very closely with the Department of Energy (DOE) to develop space science missions using nuclear power sources. As we expand such cooperation to include both radioisotope and nuclear reactor power systems, we will be calling upon more of DOE's experience base and technical infrastructure than that necessary for radioisotope work alone.

How do you plan to test the reactor to meet the schedule for this mission?

We are too early in the program definition phase to appropriately address this topic. Specific details of how the space reactor will be tested would be defined once a reactor type has been selected and the design, test, and manufacturing plans are worked out with the reactor developer.

How safe are radioisotope thermoelectric generators and reactors?

Safety is of the utmost importance and drives the overall design of radioisotope power systems and reactors, their applications, and the extensive testing, analysis and review that each system undergoes. Prior to any mission carrying nuclear material, NASA and the Department of Energy (which is responsible for development of any space nuclear systems for NASA) jointly conduct extensive safety reviews supported by safety testing and analysis. To date, NASA has safely developed, tested, and flown radioisotope power systems on 17 missions and the United States successfully launched a nuclear reactor into earth orbit in 1965. The Department of Energy and NASA place the highest priority on assuring the safe use of any nuclear power systems for space missions.

In addition to internal agency reviews for missions involving nuclear systems, an ad hoc Interagency Nuclear Safety Review Panel (INSRP) is established as part of the Presidential nuclear safety launch approval process to evaluate the safety analysis report prepared by the Department of Energy. Based upon recommendations by the Department of Energy and other agencies and the INSRP evaluation, NASA submits a request for nuclear safety launch approval to the White House Office of Science and Technology Policy (OSTP). The OSTP Director may make the decision or refer the matter to the President. In either

case, the process for launch cannot proceed until nuclear safety launch approval has been granted.

Launch approval for U.S. space missions that use nuclear systems is based on careful consideration of the projected benefits and risks of the proposed mission. The analysis of potential consequences will be based on a detailed understanding of: a) the possible accident environments; b) the response of the nuclear system in those accident environments; c) modeling how any potential releases of nuclear material might be transported; d) estimates of potential public exposure and the consequences of those exposures.

What is the danger to the public from this project? (testing, launch, flight, reentry?)

NASA's top priority is to ensure that this program and its missions can be implemented safely. Therefore, safety will be the primary driver in every aspect of the program, including spacecraft design, test, manufacture, and operation. All program activities will be conducted in a manner to reduce risk to levels as low as reasonably achievable. A hierarchy of safety objectives, requirements and engineering specifications will be established and followed during each phase of every mission.

To support these objectives, NASA will identify and mitigate risks as early in the system design process as possible and we will work continuously to ensure the safety of the public, workers, and the environment. NASA will provide opportunities for public review and comment throughout the life of the program.

What were NASA's previous failures with space nuclear systems? Have there been any failures by other organizations or nations?

None of the more than thirty radioisotope power systems and one reactor system flown by the US has failed. Three missions using radioisotope power systems have been subject to mechanical failures or human errors resulting in early aborts of each mission. In each instance, the radioisotope power system performed in accordance with its design requirements.

The first such incident occurred during the launch of a Navy navigation satellite in 1964. The Navy satellite failed to achieve orbit and burned up on reentry, which was in keeping with the safety design practice at that time. Subsequent radioisotope power systems were designed to remain intact on reentry. In 1968, NASA aborted its Nimbus-B weather satellite two minutes after launch because human error had caused the rocket to veer off course. The Radioisotope Thermoelectric Generator (RTG) was retrieved intact from the Santa Barbara Channel off the coast of California. The fuel from that system was reused on a subsequent NASA mission. Lastly, in April 1970 an RTG survived the breakup of

the Apollo 13 Lunar Module and went down intact in the 20,000 foot deep Tonga Trench.

In 1965, the US successfully launched a small nuclear reactor into Earth orbit. The reactor operated safely until an electrical failure, unrelated to reactor operation, caused it to prematurely shut down. The spacecraft is now orbiting Earth at a distance that will ensure that it does not return until its radioactive fuel has been rendered harmless due to radioactive decay.

Open literature suggests that through 1988 the former Soviet Union launched just over 30 nuclear-powered spacecraft into Earth orbit for marine radar observations. In 1978 a Soviet space reactor reentered the atmosphere and landed in Canada. Five years later, a Soviet reactor reentered over the South Atlantic Ocean. In 1996, the Russian Mars 96 spacecraft carrying an RTG failed to reach Earth orbit on launch and fell into the eastern Pacific. It is believed that some of the debris may have fallen over South America.

Who is involved in the launch pad (safety) processes?

NASA's Kennedy Space Center (KSC) has the overall management and integration responsibilities for launch site ground processing operations. However, launching NASA spacecraft is a joint effort between KSC and the Air Force at Cape Canaveral Air Force Station and Patrick Air Force Base. The Air Force is always involved in launch activities through their management of range assets. For mission launches where the spacecraft incorporates a space nuclear power system, the Department of Energy provides on-site assistance in monitoring and risk assessment.

How many RTG launches might there be in the next 10 years?

At least two NASA missions within the next decade are considering the use of radioisotope power systems, but it is expected that others may also pursue this option. The New Horizons mission to Pluto and the Kuiper Belt is in development for a launch in 2006 with a radioisotope thermoelectric generator to supply electricity to the spacecraft. The Mars Science Laboratory, in development for a 2009 launch, is considering two new radioisotope power systems currently under development by NASA and the Department of Energy – the Multi-Mission Radioisotope Thermoelectric Generator and the Stirling Radioisotope Generator. Aside from these two missions, Project Prometheus is working closely with the space science community to identify missions that could take advantage of the unique capabilities enabled by a radioisotope power system.

Is the research really worth the cost?

NASA recognizes that Project Prometheus is a major investment of taxpayers' dollars for which there should be equally significant benefits. Although difficult to

quantify in monetary terms, NASA firmly believes that the technologies developed through Project Prometheus have the potential to revolutionize our ability to explore and understand better the Universe and, ultimately, humankind's past, present, and future.

In the near term, this strategic investment in new technologies would enable an entirely new class of exploratory missions from which unprecedented science data would be returned. Propelled by extremely efficient electric thrusters, a nuclear reactor-powered spacecraft could observe multiple destinations at close range and if necessary, even modify mission objectives mid-mission based on real-time discoveries. On board, the spacecraft would carry science instruments that could peer into unknown worlds with more precision and clarity than ever before imaginable. In specific terms, the amount and quality of the data returned from the Jupiter Icy Moons Orbiter mission would dwarf that of any other robotic mission to the outer solar system. New ranges of science instruments, never used beyond Earth's orbit, would capture and return more data than the two Pioneer, two Voyager, Galileo, and Cassini missions combined.

Meanwhile, development of new radioisotope power systems delivering just over 100 watts of power would enable the Mars Science Laboratory to operate anywhere on the planet, regardless of the location of the sun, for months or years rather than days or weeks. Similar power sources could provide electricity for small-to-medium size space missions such as those proposed for New Horizons. Smaller power systems under consideration by NASA, from milliwatts to several watts, would provide mission planners a full complement of long-lived, rugged, reliable power sources. There will likely be significant technological benefits to areas outside of space exploration as well.

In the long term, the technologies developed in support of the Jupiter Icy Moons Orbiter mission could be evolved to the larger power and propulsion systems necessary to support human exploration beyond Earth orbit. Additionally, the knowledge and technologies developed through Project Prometheus-sponsored research and development will have broad applications throughout NASA, other parts of government, academia, and the private sector.

For over thirty years, NASA has relied on the same set of power and propulsion systems to explore the solar system and beyond. Project Prometheus is the investment necessary if NASA is to take a major step forward in our quest to explore our solar system and search for life, and through its groundbreaking technologies and missions would provide an inspiration to the next generation of students and explorers.